



# Lake Tahoe TMDL

## Overview of Science Program & Key Findings

Implementers Workshop  
January 29, 2008



**Lake Tahoe TMDL Science Results**

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# Lake Tahoe TMDL Research Program

1. Proactively address critical gaps in scientific understanding of Lake Tahoe's clarity loss.
2. Develop science-base approach for pollutant load reduction.
3. Develop tools to inform management decisions.
4. Integrate air, watershed and lake processes in a modeling framework.



# Regional, National & International Experts from a Variety of Research/Technical Organizations

UC Davis

DRI

UNR

CARB

US ACOE

USGS

USDA - Nat. Sed. Lab

Tetra Tech, Inc.

Hydroikos

GeoSyntec

Lahontan

NDEP

Caltrans

NDOT

**nhc**

2NDNATURE

IERS

Valley+Mountain Consulting

Entrix

Countess Environmental

Environmental Incentives

USDA - LTBMU

USDA - NRCS

US NPS

US EPA

TRPA

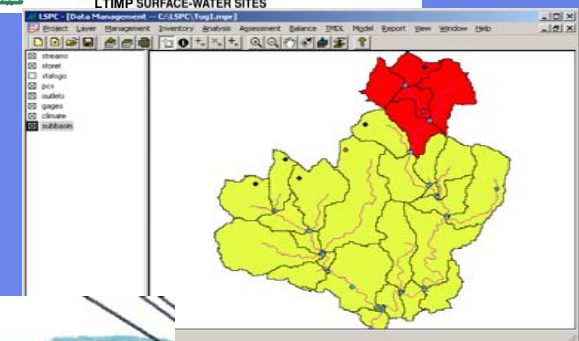
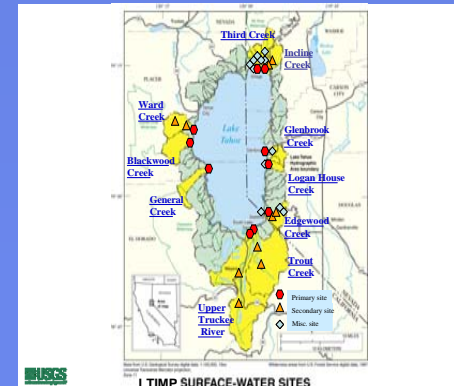
NTCD

CTC



# Scientific Approaches

- Historic Tahoe data
- Literature
- New monitoring
- Lab experiments
- Field experiments
- Demonstration projects
- Statistical analyses
- Modeling - with verification
- Best professional judgment



# Use of Scientific Models for Management

## Atmospheric

- CARB - deposition modeling
- UCD DELTA - LTAM

## Upland

- Tetra Tech - LSPC (hydrology and loading)
- Hydroikos - statistical modeling
- GeoSyntec/nhc - SWMM (stormwater), PLRM

## Groundwater

- USACOE - load modeling

## Stream Channel Erosion

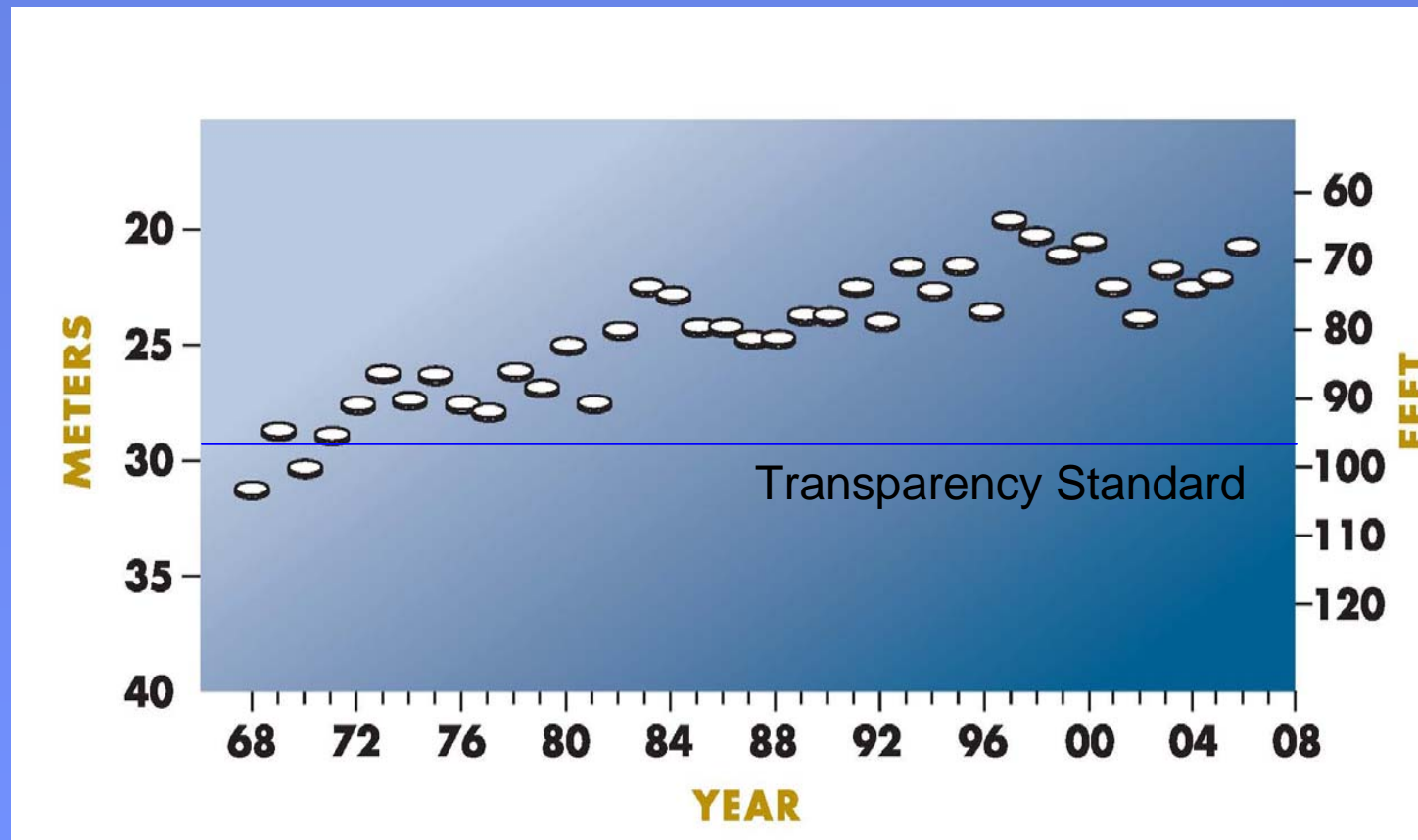
- Nat. Sed. Lab - CONCEPT/AnnAGNPS

## Lake Response

- UC Davis - Lake Clarity Model



# Current Clarity Data



# Pollutants of Concern

- Very fine sediment particles ( $< \sim 20 \mu\text{m}$ )
- Nutrients (N&P) fuel algae

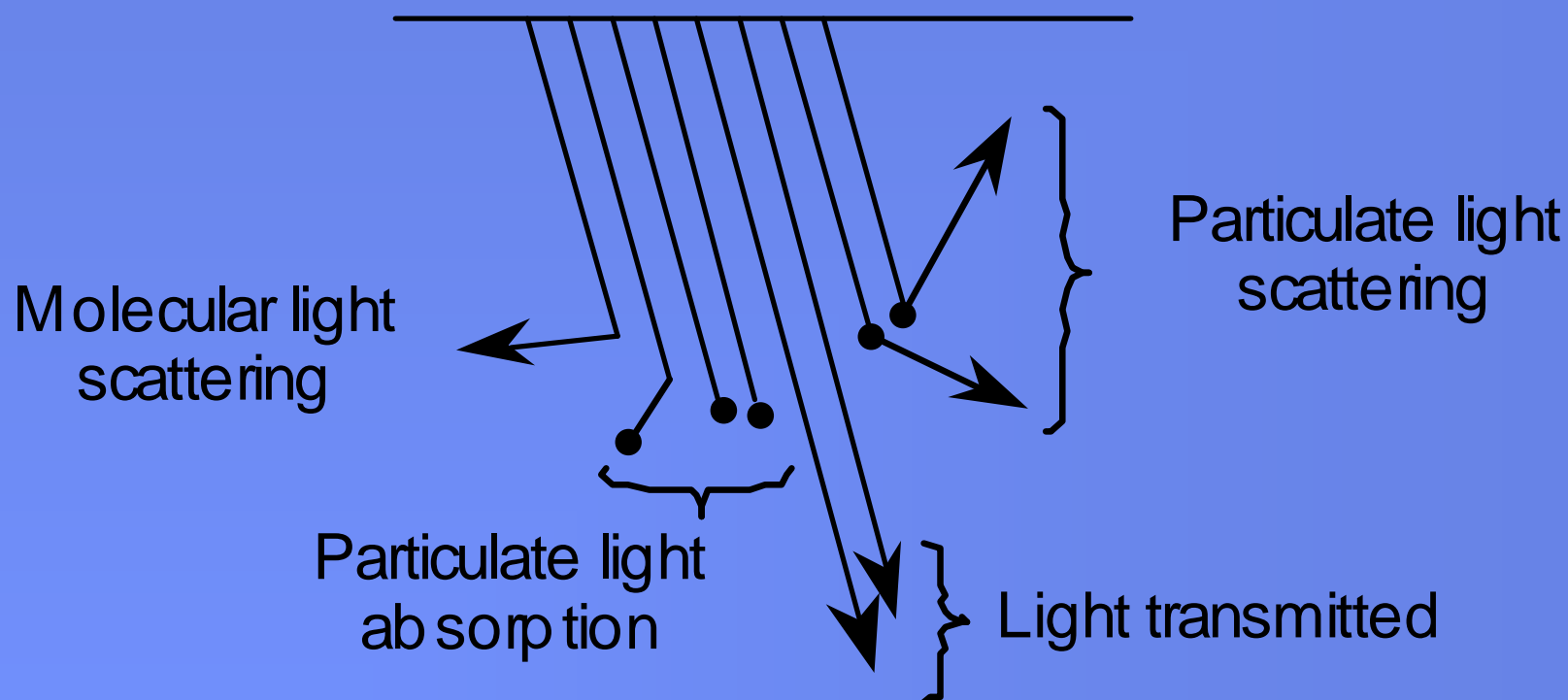


# New Science - Fine Particles

- Role of fine particles first justified by science - (1999)
- Lake sampling immediately initiated - (1999)
- Continued lake particle characterization - (1999, 2000, 2002, 2003)
- Optical model for clarity based on particles - (2004)
- TMDL stormwater monitoring - (2003-04)
- Stream particle load - (2002-03)
- Atmospheric deposition - (2002-03)



# Conceptual Diagram of Light Scattering and Absorption



Number, Size, Composition & Distribution



# Contribution of Fine Sediment, Algae, DOM and Water to Tahoe's Clarity Attenuation

- Lab results & optical model shows the following contributions to clarity:

Soil particles -> 55 - 60%

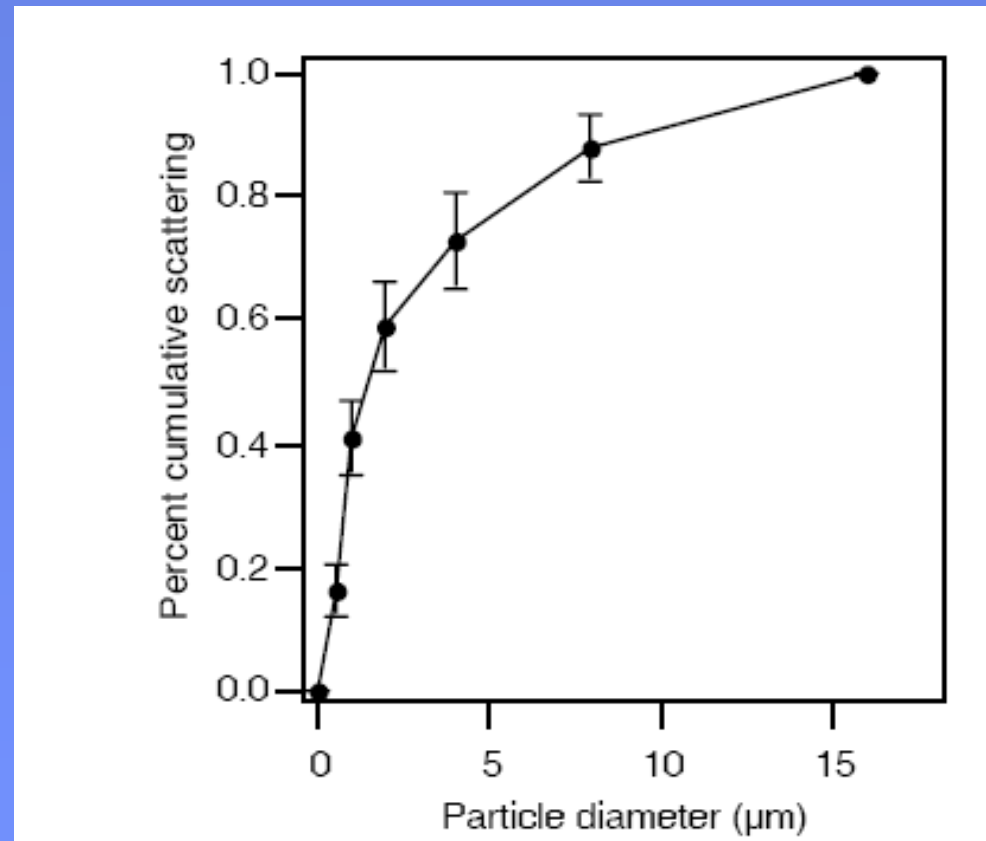
Organic Particles -> 20 - 25%

Water and DOM -> 15 - 20%

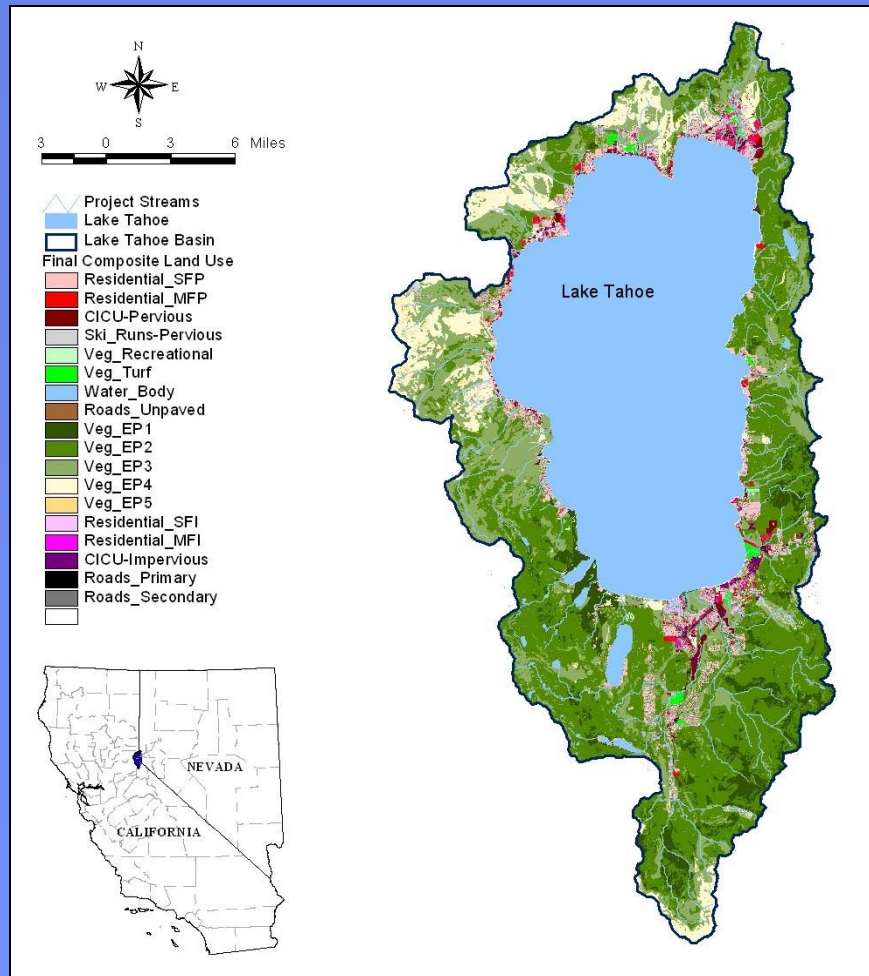
- Field monitoring shows strong relationship between number of particles and Secchi depth



# Contribution of Particle Size Classes to Total Light Scattering



# Reliable GIS Land-Use Layers



Tetra Tech



Minor & Cablk

Layers have wide-spread use



# Distribution of Land Use and Land Cover Classifications in the Tahoe Basin

Land Use / Land Cover (LULC)	Area in Basin (hectares)	Proportion of Basin	Imperviousness of LULC
Commercial/Institution/Commun./Utility	1,112	1.3%	36%
Multi Family Residential	1,153	1.4%	27%
Single Family Residential	4,037	4.9%	18%
Transportation, Primary Roads	231	0.3%	100%
Transportation, Secondary Roads	1,105	1.3%	100%
Transportation, Unpaved Roads	154	0.2%	--
Vegetated, Recreational and Turf	1,044	1.3%	--
Vegetated, Unimpacted	72,971	87.7%	--
Water Bodies (not including Lake Tahoe)	1,380	1.7%	--



# Atmospheric Deposition

	Dry Deposition (MT/yr)	Wet Deposition (MT/yr)
<b>Nitrogen</b>		
NO3	29	18
NH4	87	14
DIN	116	32
DON	31	31
TON	39	32
PN	7	<1
<b>Total N</b>	<b>155</b>	<b>63</b>
<b>Phosphorus</b>		
SRP	1.3	1.0
<b>Total P</b>	<b>3.5-5.4</b>	<b>2.6</b>
<b>Particulate Matter</b>		
Fine (<2.5 µm)	60	74
Course (>2.5-10 µm)	169	69
Large (>10 µm)	357	20
<b>Total PM</b>	<b>586</b>	<b>163</b>

UCD & CARB



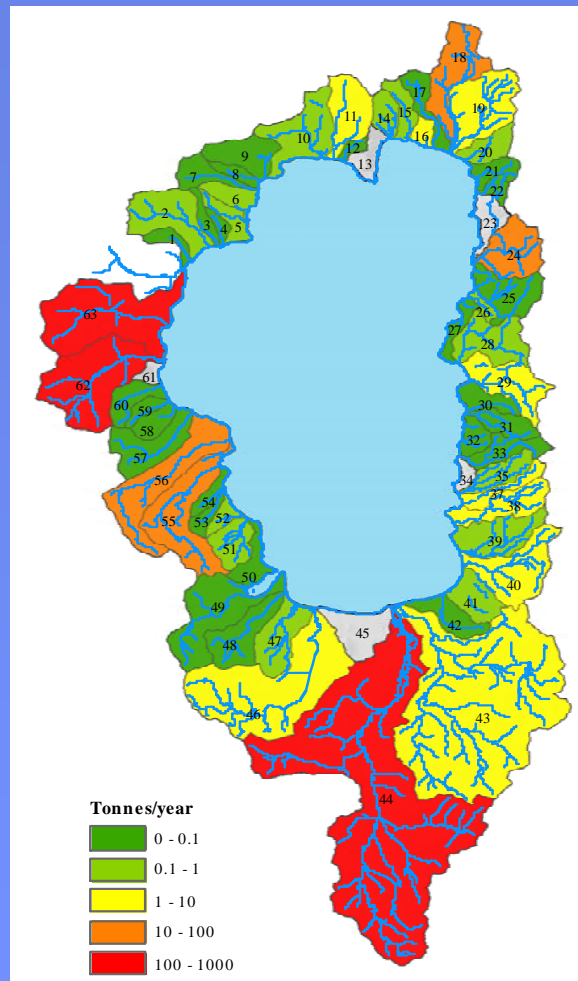
# Agreement in Groundwater Loading

Constituent	US ACOE 2003	Thodal 1997
Total Dissolved Nitrogen (kg/yr)	50,000	60,000
Total Dissolved Phosphorus (kg/yr)	6,800	4,000
Discharge Rate (m <sup>3</sup> /yr)	$6.4 \times 10^7$	$4.9 \times 10^7$

Assumes no particles >0.5  $\mu\text{m}$  enter via GW



# Stream Channel Erosion



Simon et al.

First time that total sediment and fine sediment loading from stream bed and bank erosion has been studied



# Upland Loading

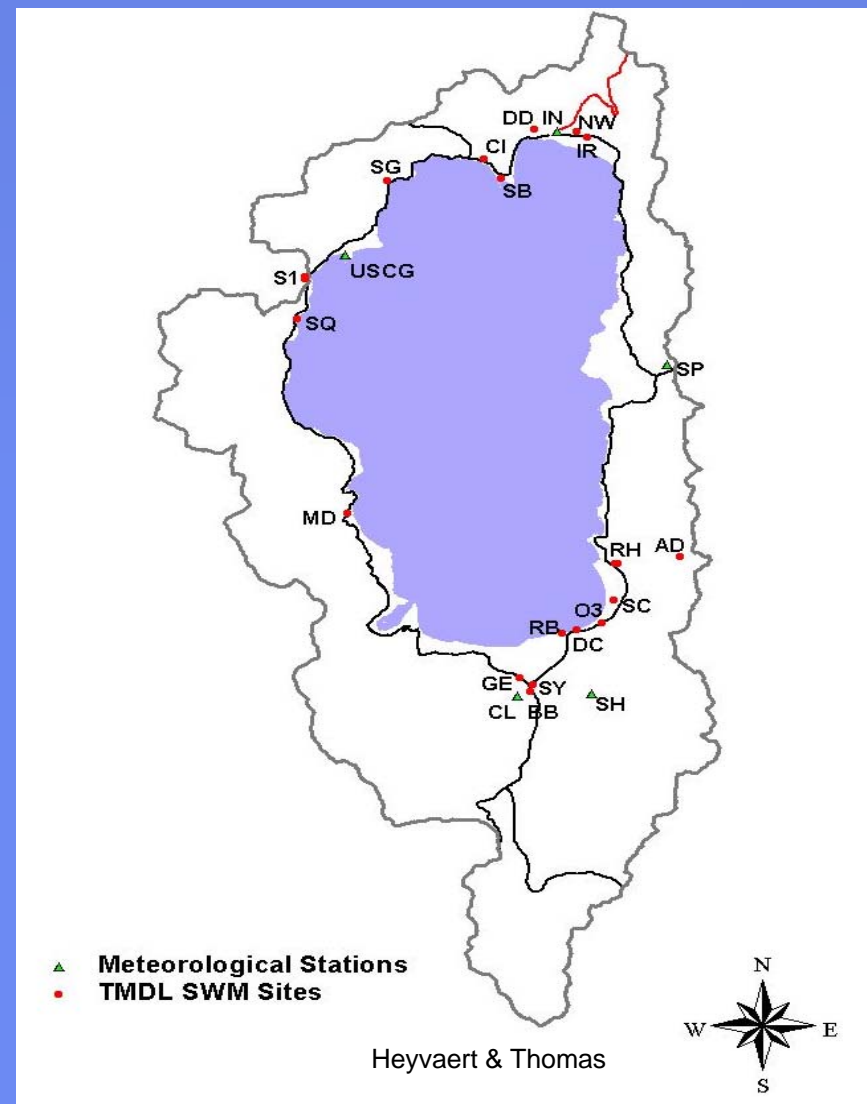
## Watershed Model

- (1) Hourly data from 9 SNOTEL sites drives hydrology
- (2) Validated well at scales of storms, monthly and annual
- (3) Total N/P loads modeled - each partitioned using field data
- (4) Modeled loads usually within 10-15% of LTIMP measurements
- (5) Modeled TSS and mass  $<63 \mu\text{m}$ , but not adequate for # of particles  $<20 \mu\text{m}$  by size class.
- (6) Rabidoux & Schladow measured particles in LTIMP streams and used model flow to estimate load

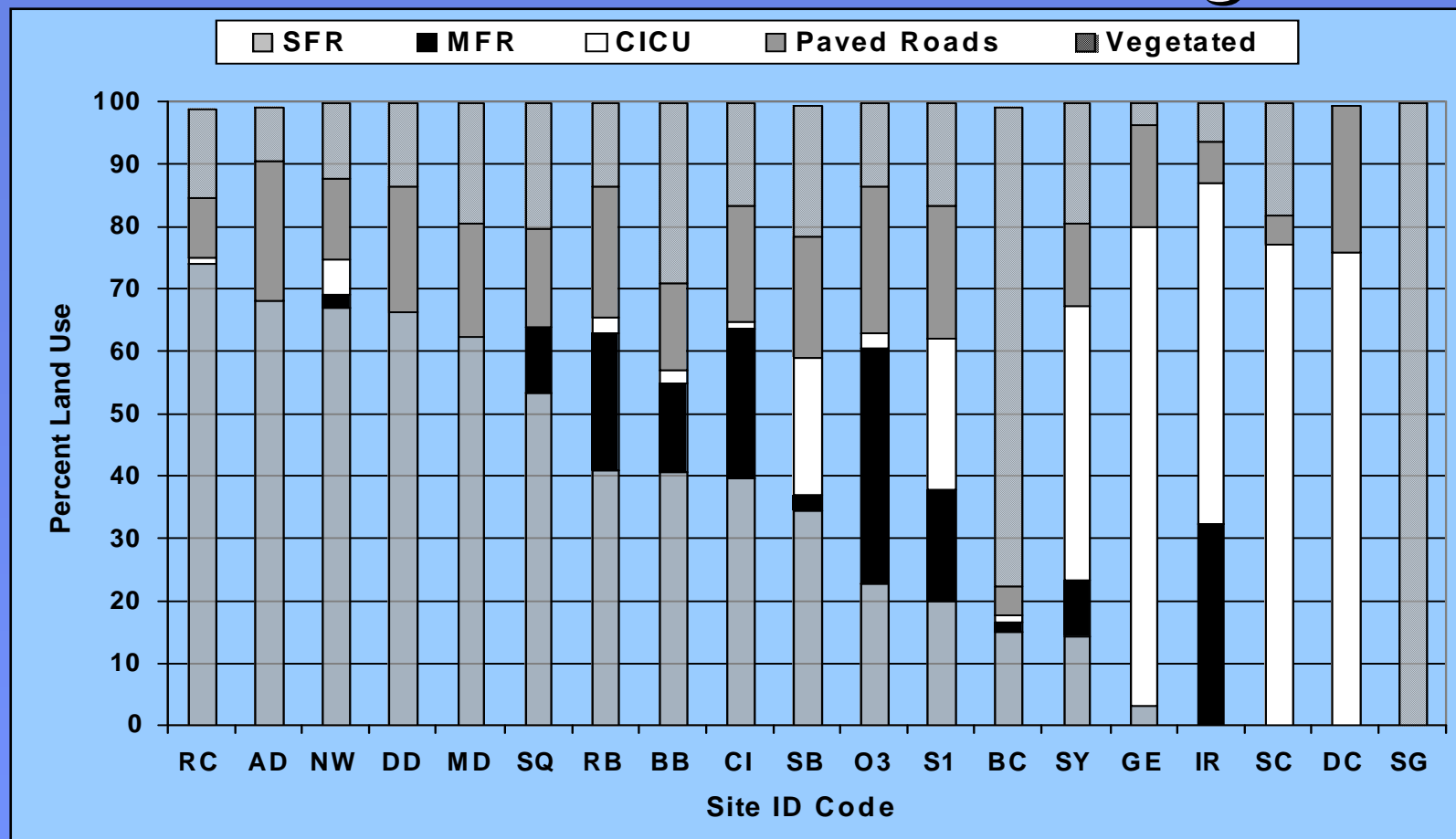


# Stormwater Monitoring

- First basin-wide monitoring program for stormwater
- Similar scope as stream monitoring
- 2003-2004



# Stormwater Monitoring

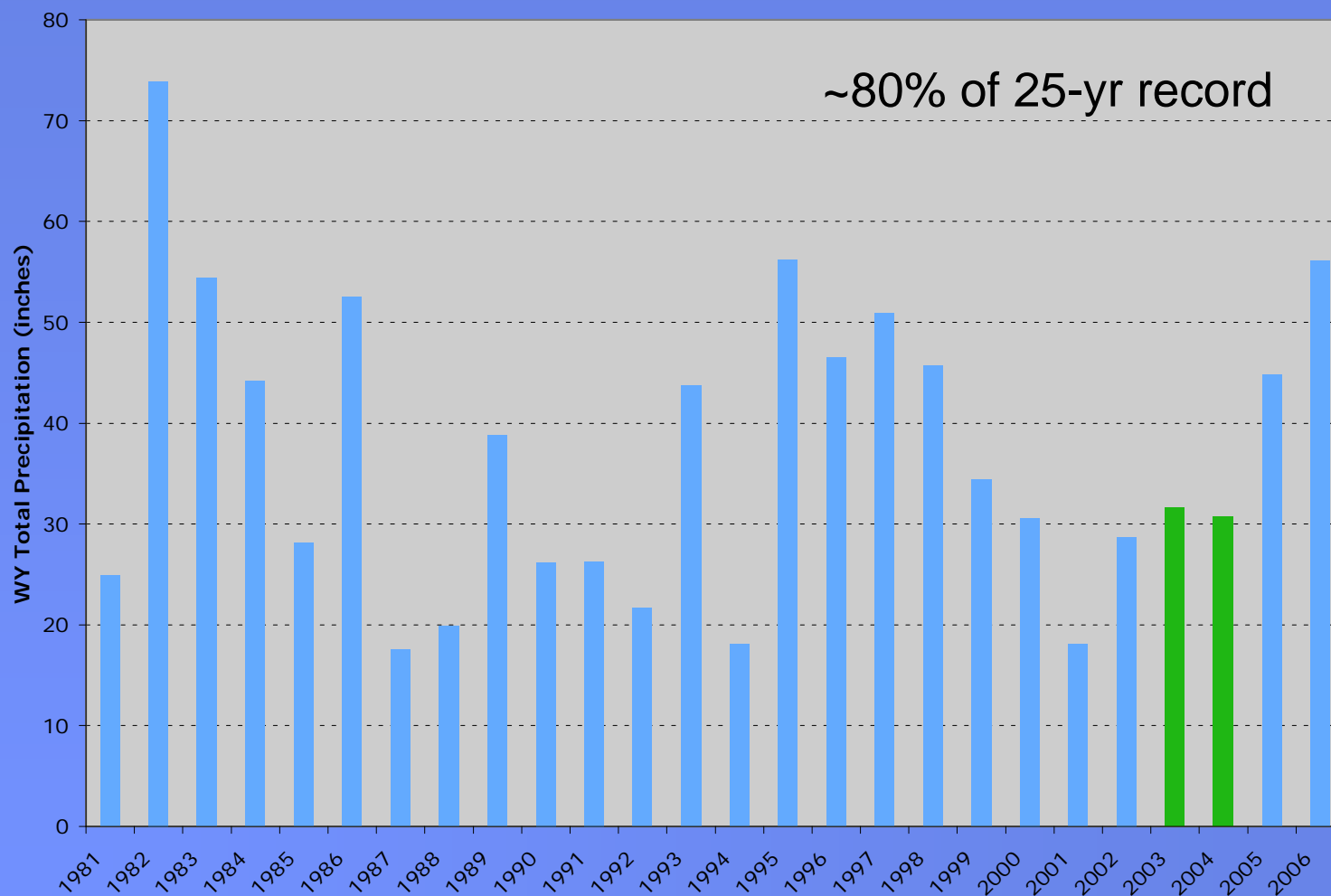


Heyvaert & Thomas

Difficult to design monitoring to target individual land use



# Precipitation During SWM

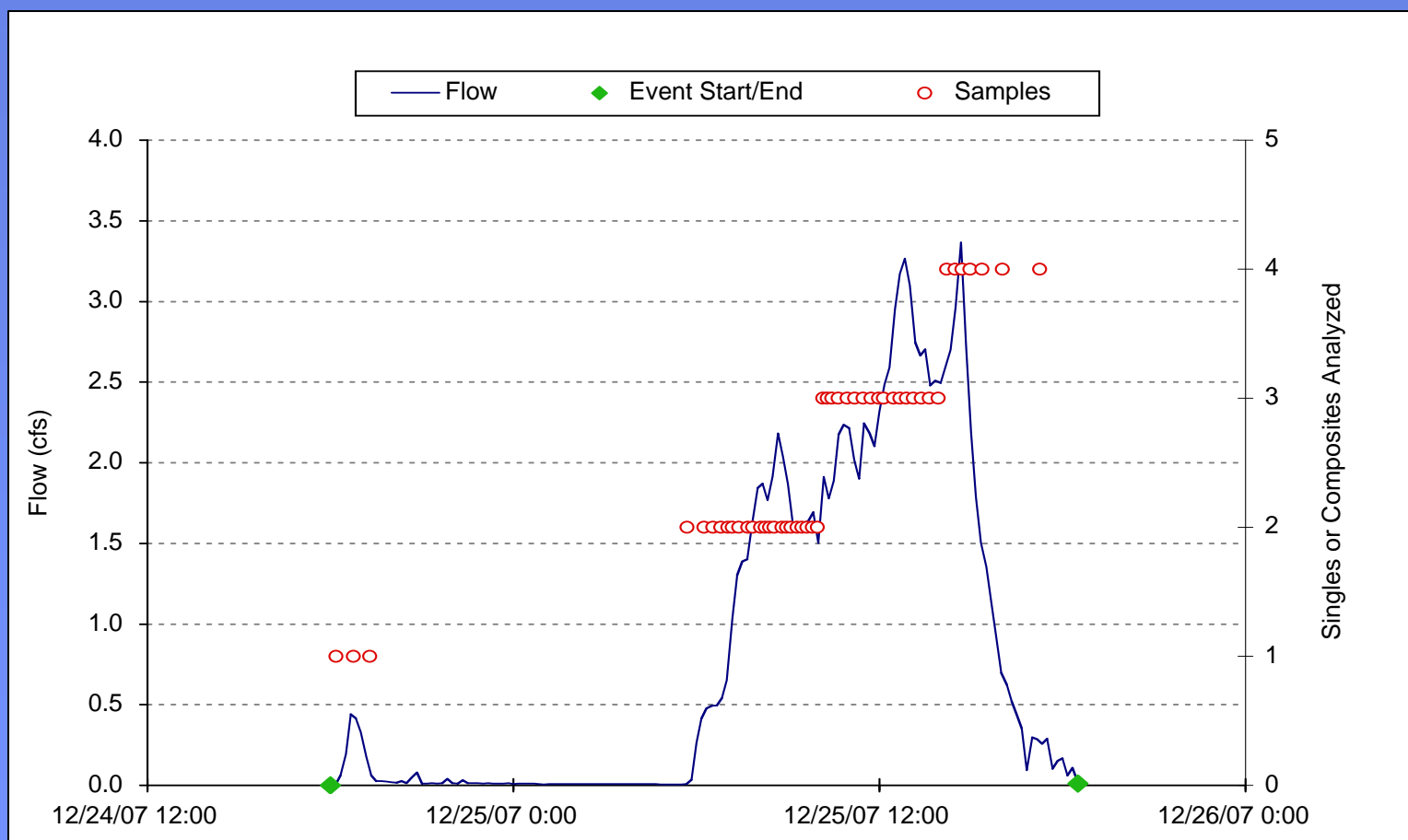


# SWM Sampling Frequency

ID	Site Name	Events	Flow (%)	Events	Flow (%)
		2003		2004	
AD	Andria Dr.	12	28%	12	12%
BB	Bonanza Ave.	17	82%	2	7%
BC	Bijou Creek	na	na	43	86%
CI	Coon Street	13	na	10	4%
DC	Don Cheapo's	15	36%	21	23%
DD	Dale Dr.	16	83%	18	37%
GE	Glorene and Eighth	na	na	7	62%
IR	IV Raley's	21	38%	26	34%
MD	Mountain Dr.	4	60%	4	3%
NW	Northwood Blvd.	15	9%	28	40%
O3	Osgood Ave.	17	68%	28	58%
RB	Regan Beach	14	86%	21	15%
RC	Roundhill 4.2	20	36%	7	32%
S1	TCWTS	24	42%	26	13%
SB	Speedboat Ave.	26	86%	32	75%
SC	SLT Casinos	3	3%	32	10%
SG	Shivagiri	na	na	16	26%
SQ	Sequoia Ave.	12	na	8	7%
SY	SLT-Y	26	94%	26	74%
mean:		16	54%	19	32%

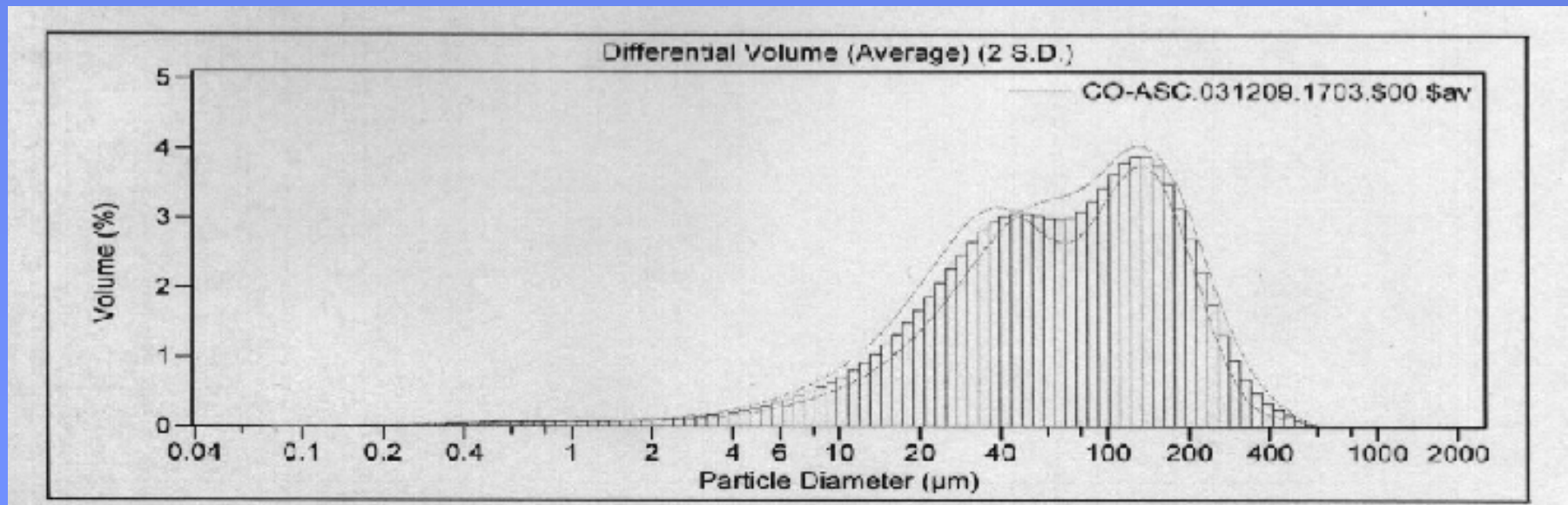


# Constant Volume Sampling for Event Mean Concentration (EMC)

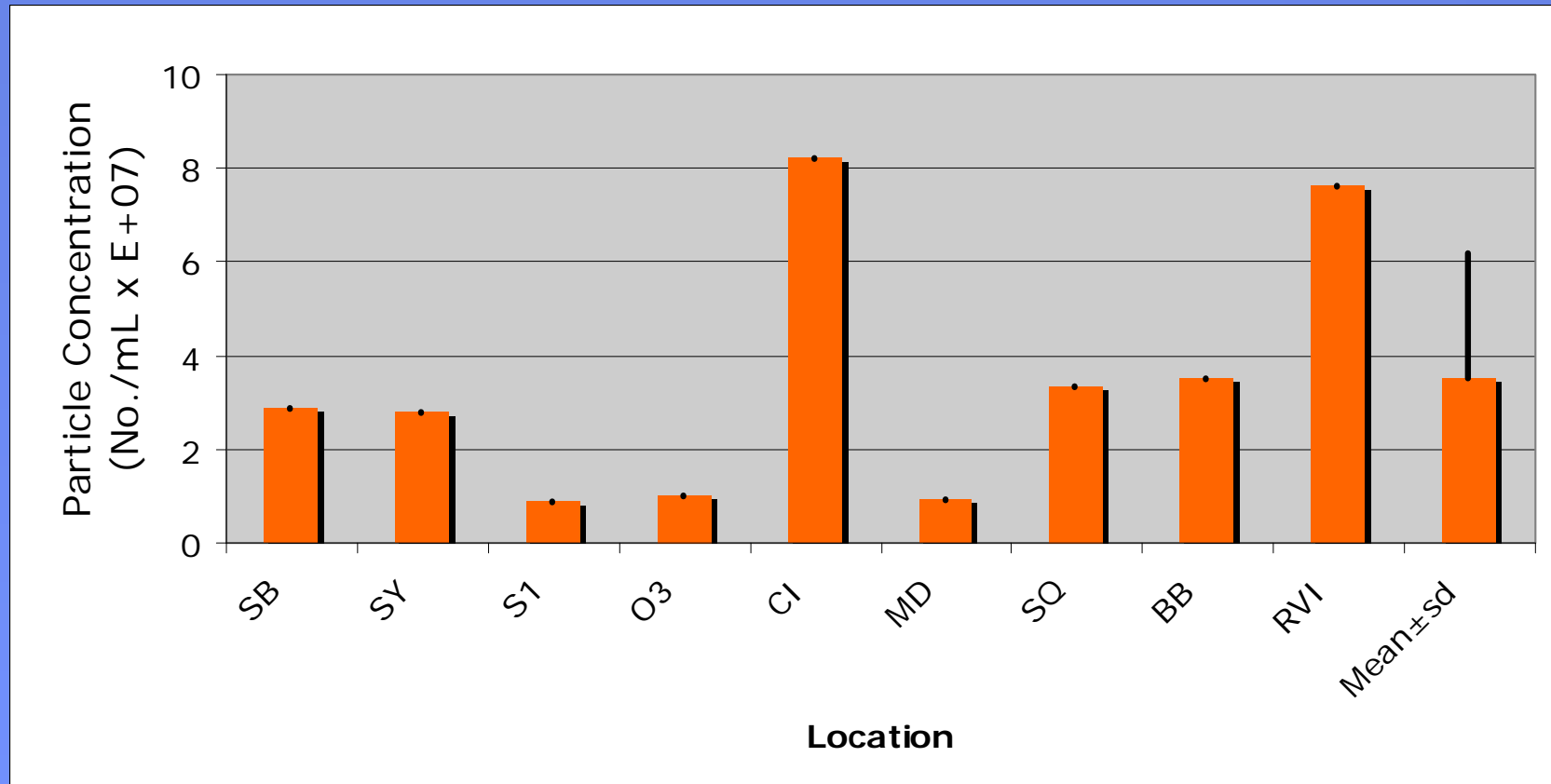


# Particle Size Distribution (PSD) Analysis in Stormwater Samples

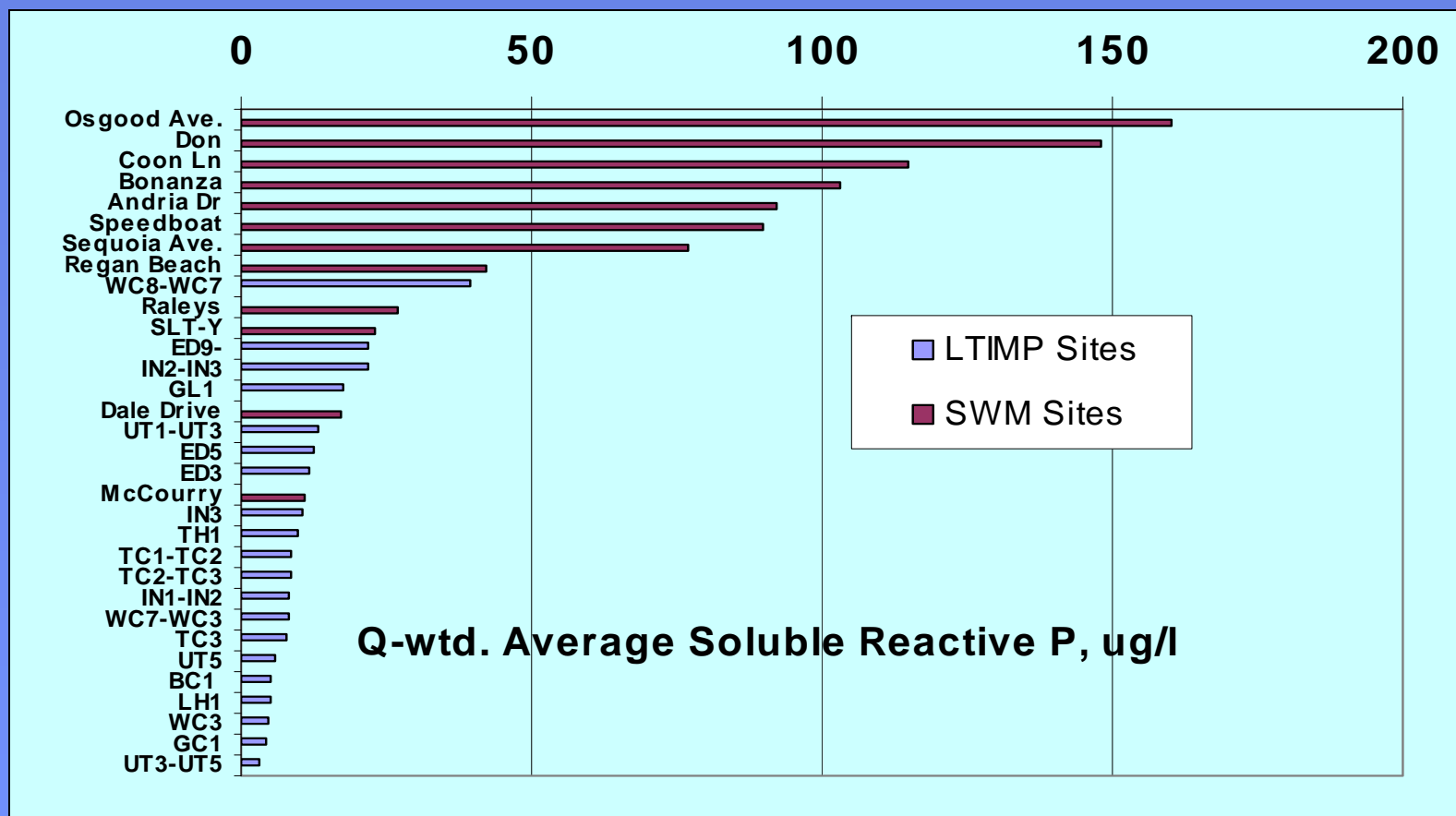
- Laser diffraction backscattering: Beckman Coulter LS 13-320
- Calculated particle number concentrations using PSD and TSS data, with assumed constants



# Urban Particle Distribution



# Stormwater Monitoring



Gunter 2005

Coats *et al.* 2008



# Event Mean Concentrations

- Used to assign runoff concentrations by land use
  - Represent basin-wide conditions **not** specific locations
  - Supported by Tahoe data or literature values
  - Field data used as starting point for calibration to LTIMP stream data
  - Applies to TSS, N & P - not fine particles
- 
- Residential (SF/MF) - Direct SWM monitoring, 2003-04
  - Commercial (CICU) - Direct SWM monitoring, 2003-04

Data Sources: Accepted QAPP; Gunter 2005; Coats *et al.* 2008



# Event Mean Concentrations

- Primary roads - Caltrans (2003); NDOT/DRI (2004)
- Secondary roads - same as MF residential
- Unpaved roads - LTBMU McKinney Rubicon Rd., Sierra Nevada Ecosystem Project (McGurk *et al.* 1996)



# Event Mean Concentrations

- Ski runs - Heavenly, Homewood & Diamond Peak data
- Turf - Adjust SF residential based on application estimates and relative lawn areas
- Harvested - Used USFS Equivalent Road Area method
- Undisturbed Forest - Monitoring, literature and calibration



# EMCs

**Can be Updated Under Adaptive Management**

Land Use Name	TN	DN	TP	DP	TSS
Residential_SF (P/I)	1.75	0.14	0.47	0.14	56
Residential_MF (P/I)	2.84	0.42	0.59	0.14	150
CICU (P/I)	2.47	0.29	0.70	0.08	296
Roads_Primary	3.92	0.72	1.98	0.10	952
Roads_Secondary	2.84	0.42	0.59	0.14	150
Ski_Runs-Pervious	0.36	0.13	0.12	0.04	271
Veg_EP1	0.16	0.01	0.03	0.03	14
Veg_EP2	0.16	0.01	0.03	0.03	38
Veg_EP3	0.16	0.01	0.03	0.03	101
Veg_EP4	0.16	0.01	0.03	0.03	271
Veg_EP5	0.16	0.01	0.03	0.03	727
Veg_Recreational	1.04	0.01	0.63	0.21	460
Veg_Burned	2.34	0.01	1.52	0.48	1015
Veg_Harvest	2.34	0.01	1.52	0.48	1015
Veg_Turf	5.48	0.45	1.46	0.45	12
Roads_Unpaved	2.34	0.01	1.52	0.48	1015



# Particle Size Distribution by Major Source Category

## *Atmospheric Deposition*

- Particulate matter (PM) loading estimated by CARB (2006)
- Soil-based PM reported as <2.5, 2.5-10 and >10-35  $\mu\text{m}$
- 37% of PM<2.5 found to be soil-based, assumed 100% for others
- Conversion to particle # for 7 clarity model classes needed
- Assuming soil particles are spherical with density of 2.56  $\text{g}/\text{cm}^3$  weight converted to number
- Interpolated to 7 size classes



# PSD by Major Source Category

## *Stream Runoff*

- TSS output from Watershed Model not adequate for particles  $<20\text{ }\mu\text{m}$
- Rabidoux & Schladow measured PSD on all samples from the 'mouths' of 10 LTIMP streams in 2002 and 2003
- Regressions between streamflow and PSD developed
- Remaining streams were grouped with an LTIMP stream based on location and land-use
- Daily streamflow from Watershed Model used to estimate particle load for 7 size classes



# PSD by Major Source Category

## *Urban Intervening Zone Flow*

- Stream Flow PSD regressions not applicable for urban runoff
- Direct LTIMP and SWM field data show particle concentrations (#/mL) ( $< \sim 20 \mu\text{m}$ ) much higher in urban runoff
- Multiplication factor for urban particle flux was developed
- SWM data from 9 urban sites used

Urban Runoff	3.5E+07
Streamflow	1.3E+05
Lake	7.0E+03



# *Urban Intervening Zone Flow*

## Calculation of Multiplication Factor

- Mean IZ flow (modeled) =  $1 \times 10^6 \text{ m}^3$  (1994-2004)
- IZ Flow  $\times 3.5\text{E}+07 = \sim 3.5\text{E}+20$  particles per year
- Applying Rabidoux's eqns. to IZ we get  $1.1\text{E}+10^{18}$

$$3.5\text{E}+20 / 1.1\text{E}+18 = \underline{319} \text{ (0.5-16 } \mu\text{m)}$$

$$7.7\text{E}+16 / 3.5\text{E}+15 = \underline{22} \text{ (>16-<63 } \mu\text{m)}$$

- Modeled flow, Rabidoux's eqns. and multipliers used to determine basin-wide loading



# Particle Size Distribution by Major Source Category

## *Stream Channel Erosion*

- Particle load to Lake included in stream runoff estimates
- Watershed Model found that ~30% of stream load came from stream channel erosion



# Review of Approach for Fine Particle Loading

## Watershed Loading to Lake for Clarity Model

- Regressions developed for flow and PSD based on field data; modified for the collective urban region
- Modeled urban and non-urban flows used to estimate PSD loading from these broad land uses
- Clarity Model does not need to consider more specific land uses



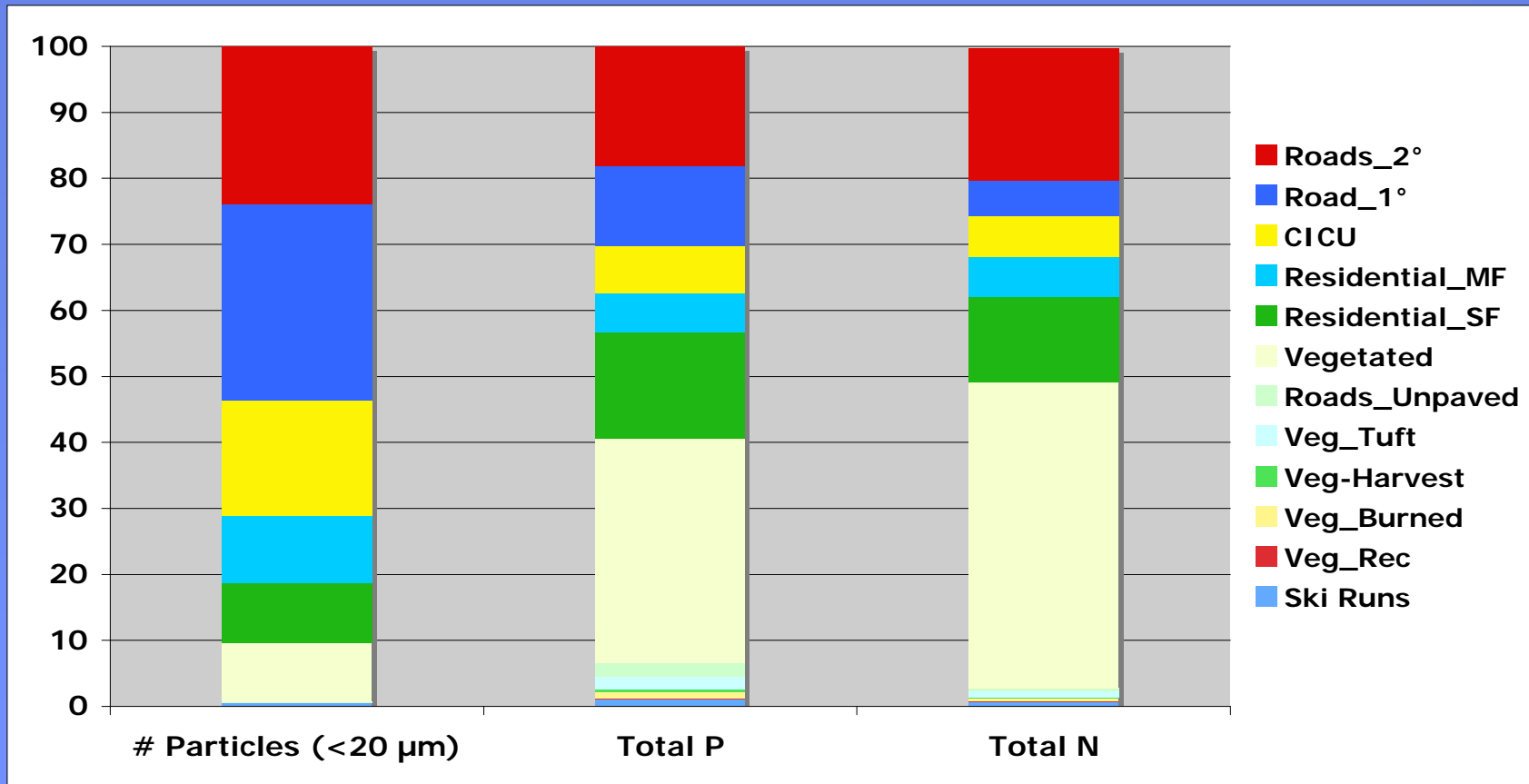
# Review of Approach for Fine Particle Loading

## Apportioning Particle Loading by Specific Land Use

- Since land use specific urban monitoring was not feasible, apportioning was done based on TSS loading results from the Watershed Model for the various land uses
- TSS output needed to be expressed in terms of particle number <20  $\mu\text{m}$ 
  - (1) Fraction of TSS <63  $\mu\text{m}$  (mass)
    - For urban residential and CICU it was measured by SWM
    - For non-urban, data from LTIMP stream headwaters
    - Assumed paved roads were similar to SWM measurements
  - (2) <63  $\mu\text{m}$  mass from modeled land uses was converted to PSD <20  $\mu\text{m}$  based on particle #, volume of particles in a size class and soil density



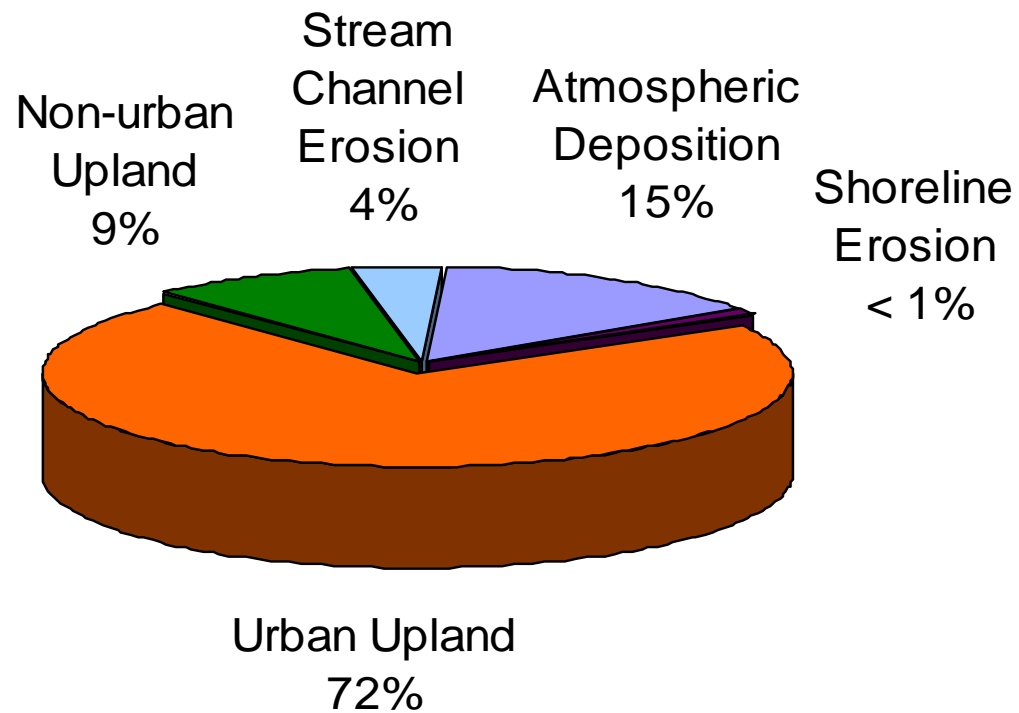
# Upland Loading



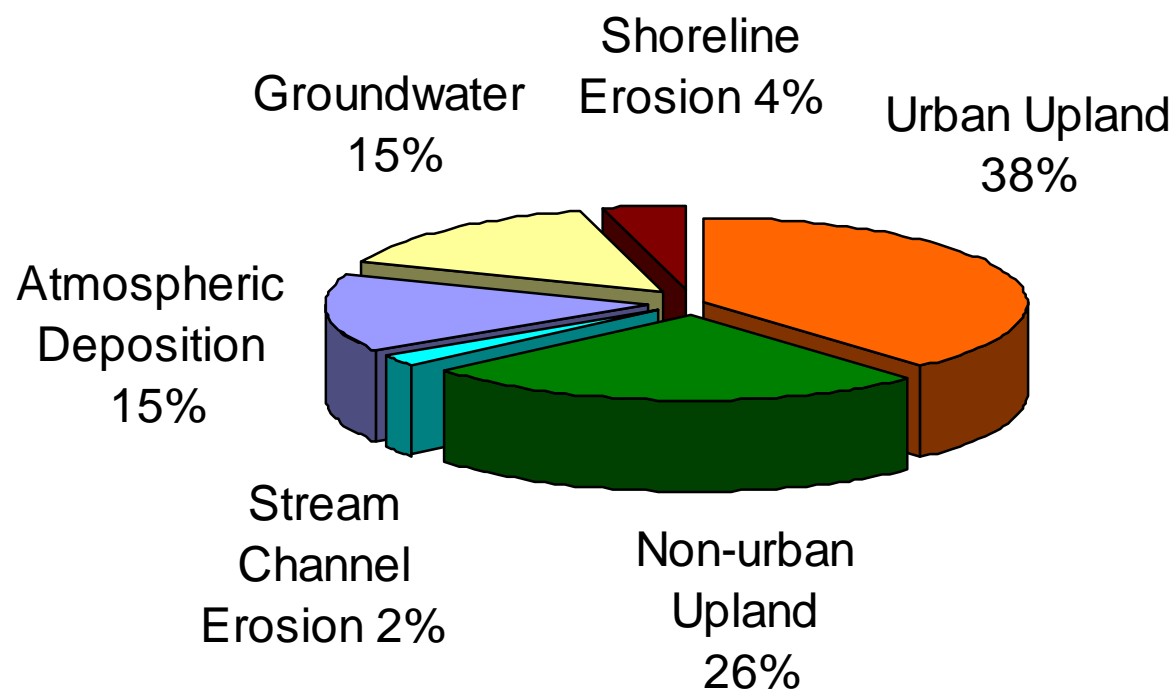
From Tetra Tech



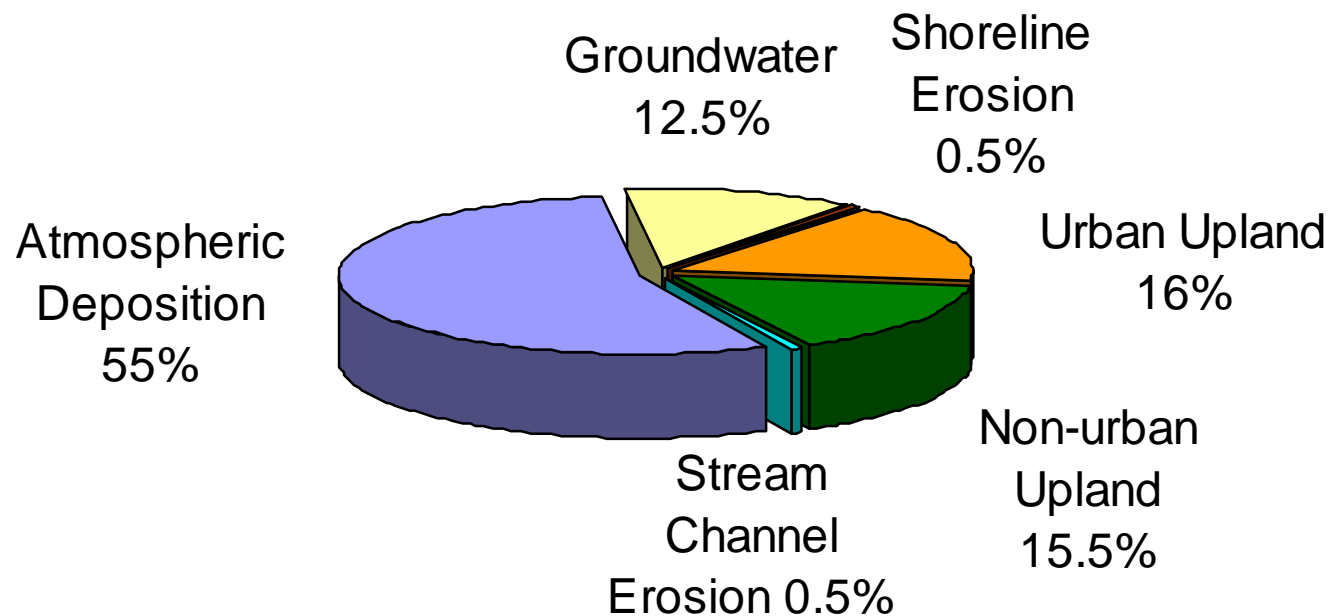
**Fine Sediment Particle Number Estimates  
(particles less than 20 micrometers):  
Percent Contribution per Source Category**



## Total Phosphorus Estimates: Percent Contribution per Source Category



## Total Nitrogen Estimates: Percent Contribution per Source Category



# Assumptions Based on Available Data

- Concentrations at SWM sites same as delivered to Lake
- Average EMCs applied basin-wide
- Relationship between average EMCs and flow were representative for different events, seasons and precipitation years
- When particles were not directly measured, they could be estimated from mass using a density of  $2.56 \text{ g/cm}^3$  with a spherical shape
- Modeled flow used to estimate urban & non-urban loading
- LTIMP headwaters represents non-urban particle loading



# Confidence & Uncertainty

Source Category		Total Nitrogen (metric tons/year)	Total Phosphorus (metric tons/year)	Number of Fine Sediment Particles (x10 <sup>18</sup> )
Upland	Urban	63	18	348
	Non-Urban	62	12	41
Atmospheric Deposition	(wet + dry)	218	7	75
Stream Channel Erosion		2	<1	17
Groundwater		50	7	NA **
Shoreline Erosion		2	2	1
TOTAL		397	46	481

## High

- Based on reliable and extensive field data or modeling supported by extensive field data.
- Peer-reviewed studies exist specifically for the Tahoe Basin.
- Weight of evidence provided by similarity to other independent studies for Lake Tahoe.
- Scientific reasoning supported by TMDL Team.
- Additional studies not likely to yield significantly different results.



# Confidence & Uncertainty

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Shoreline Erosion		2	2	1
TOTAL		397	46	481

## Medium

- Estimates based on field data or modeling; however, the supporting data base is either not extensive and/or comprehensive.
- Primarily non peer-reviewed studies exist for the Tahoe basin.
- Weight of evidence provided by studies for Lake Tahoe is limited.
- Additional studies will improve our understanding but not likely change broad-based management strategy.



# Confidence & Uncertainty

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## Low

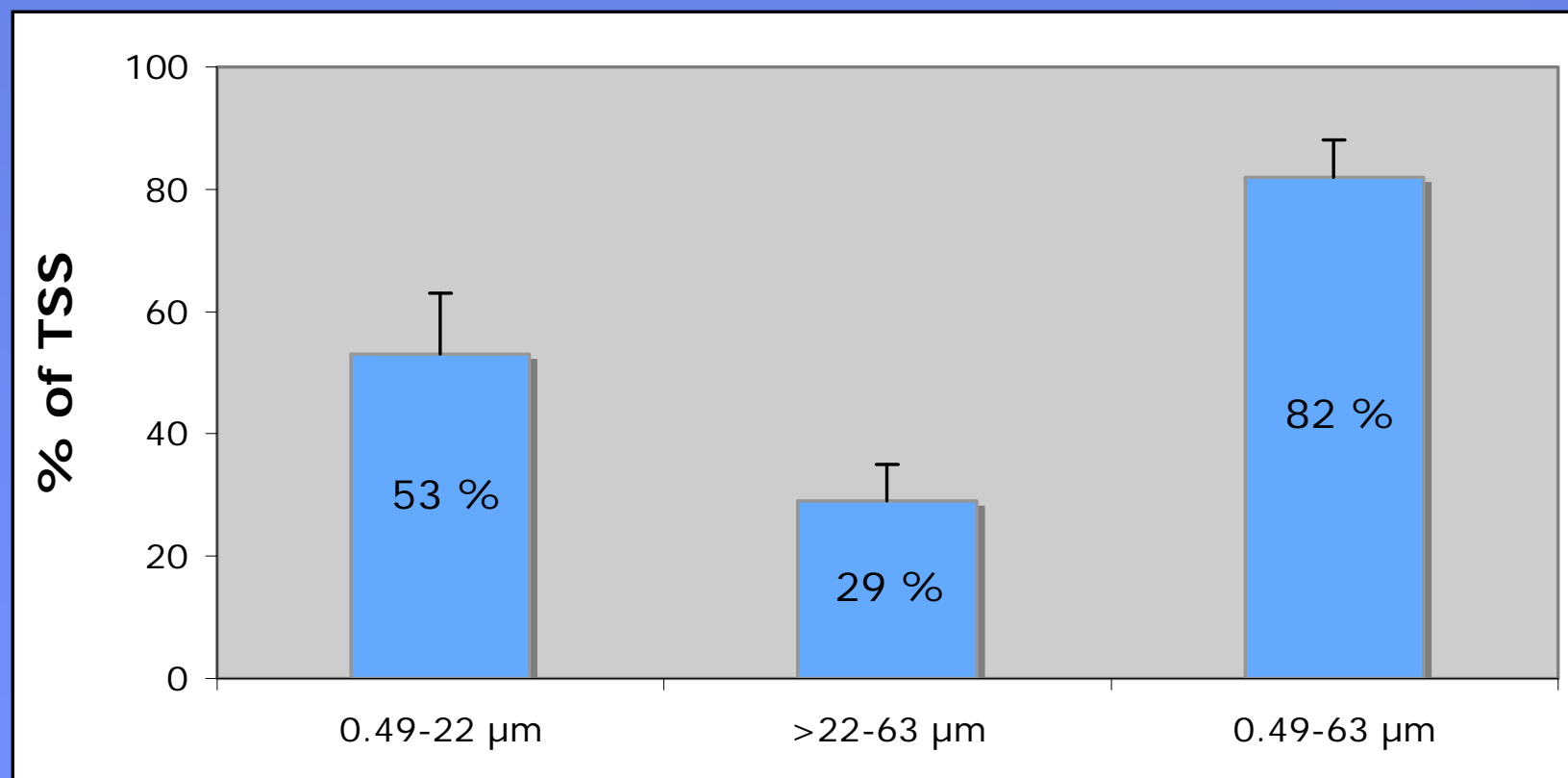
- Estimates based on a single study that was considered preliminary or not enough data was collected.
- Additional studies are needed to support management decisions.







# Size Distribution of Urban Fine Particles

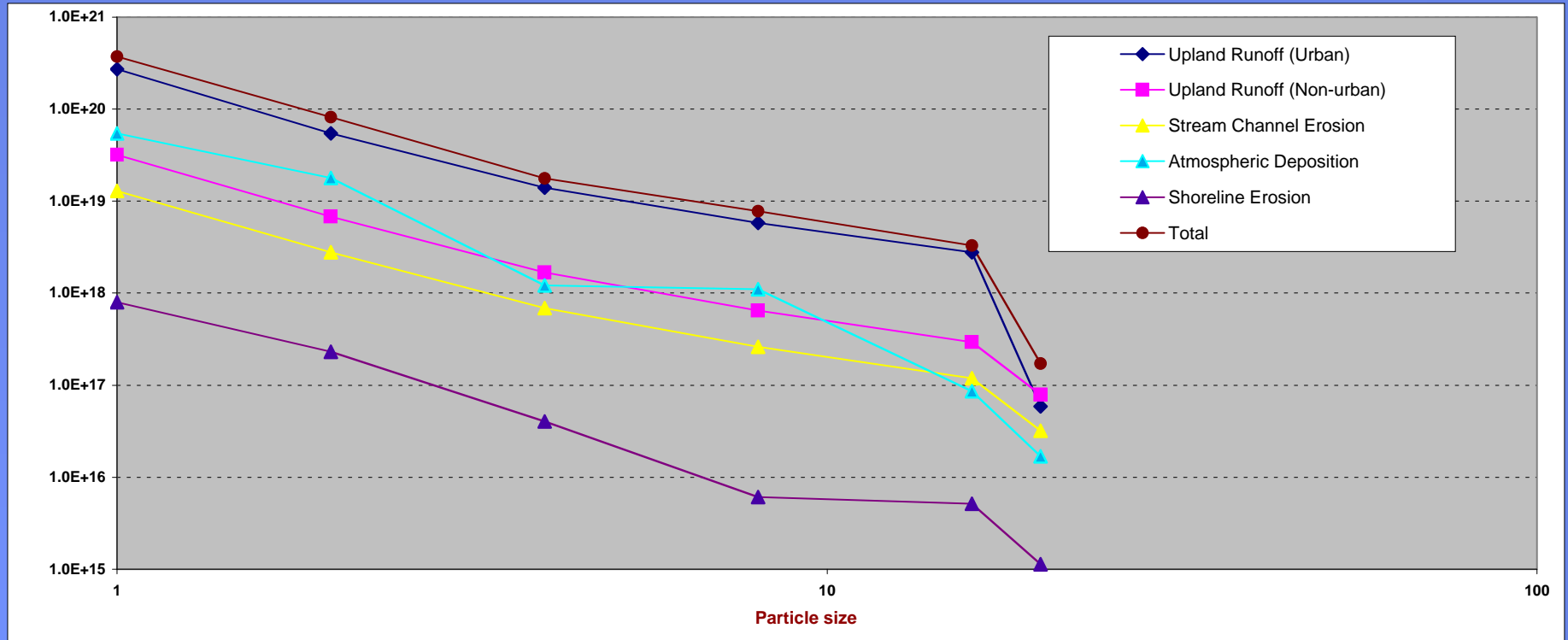


From Tetra Tech, UCD & DRI



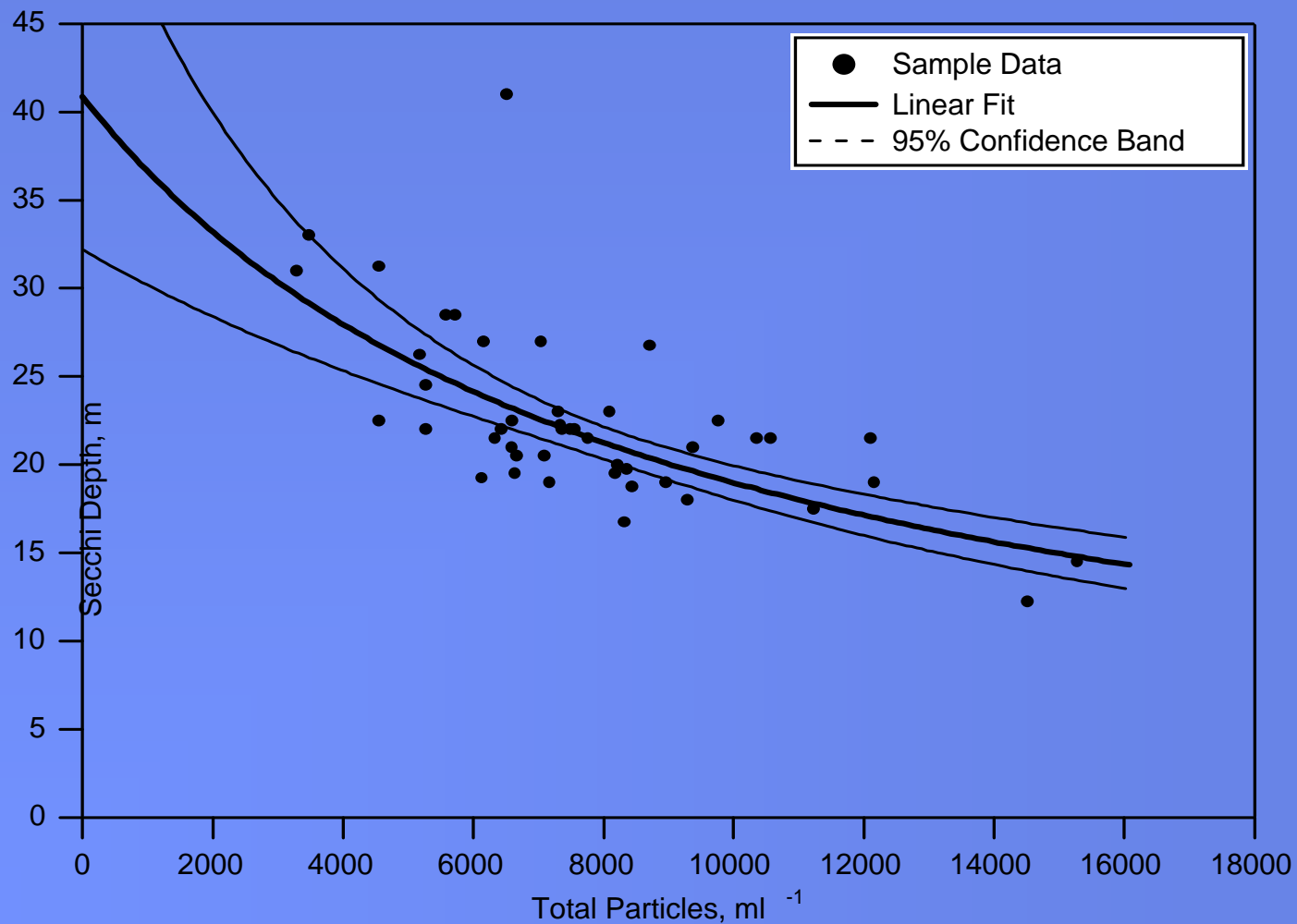
**Lake Tahoe TMDL Science Results**

# Estimated Particle Load Numbers



Lake Tahoe TMDL Science Results

# Relationship Between Total # Particles and Secchi Depth



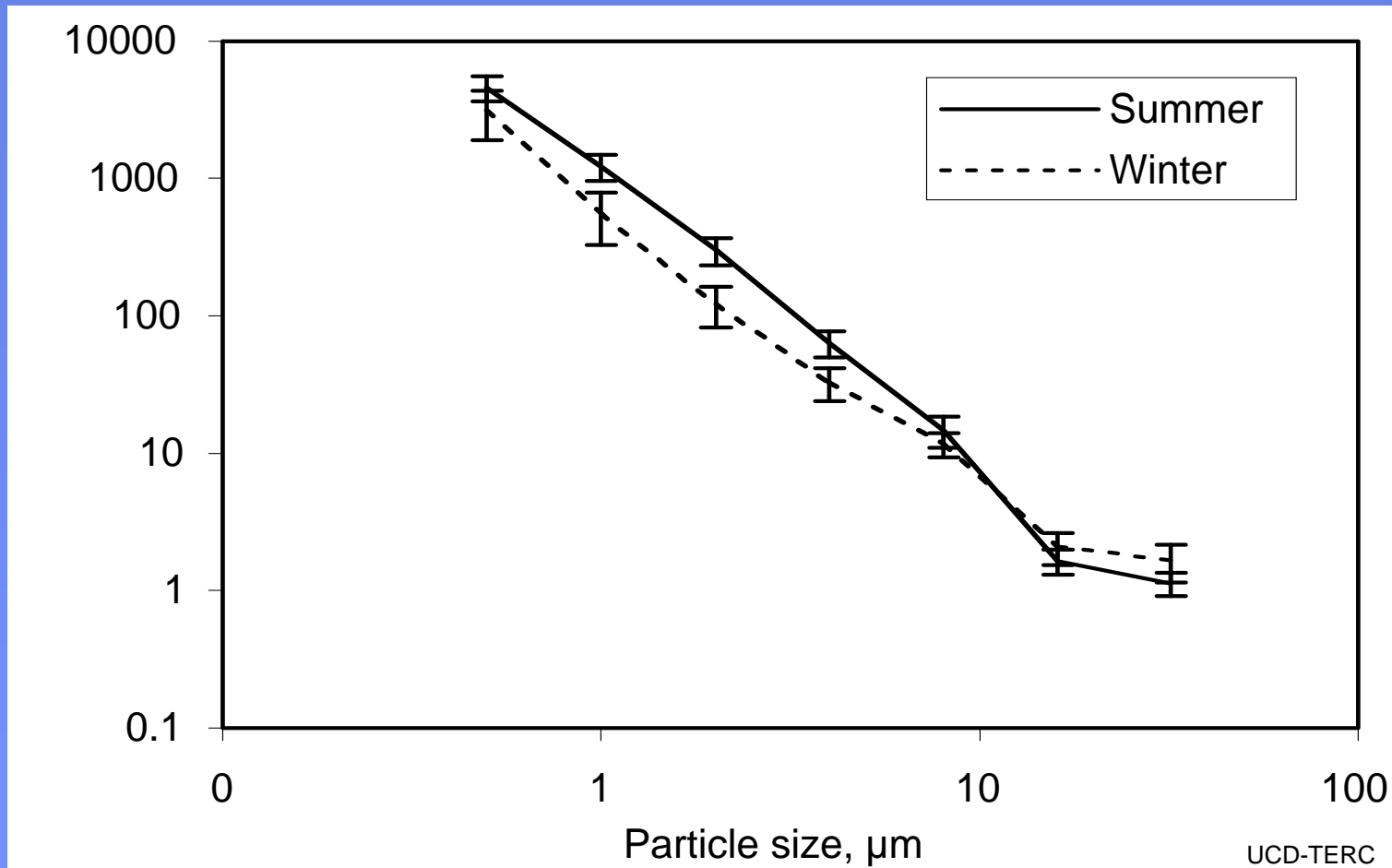
# What do Particles Look Like



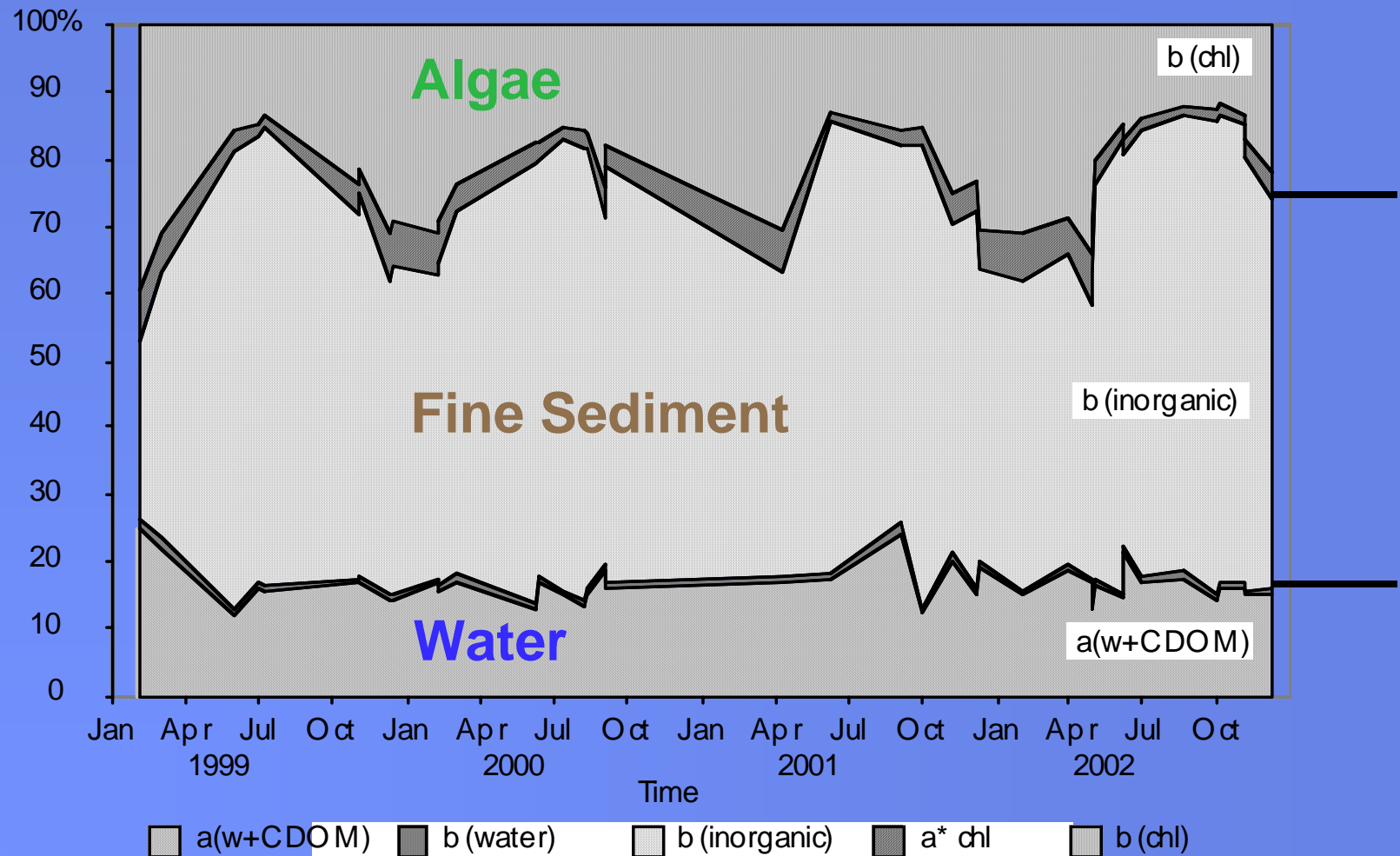
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**Lake Tahoe TMDL Science Results**

# Particle Distribution in Lake Tahoe



# Contribution of Fine Sediment, Algae, DOM and Water to Tahoe's Clarity Attenuation



Lake Tahoe TMDL Science Results

# Features of TMDL Science Program

- Largest scientific effort at Lake Tahoe
- Significant at national level
- Involves >150 people
- Significant financial commitments
- Creating tools that will last and evolve with the continual improvement cycle
- Made possible by important financial commitments to Lake Tahoe

